IN-DEPTH SURVEY REPORT:

A LABORATORY EVALUATION OF PROTOTYPE ENGINEERING CONTROLS DESIGNED TO REDUCE OCCUPATIONAL EXPOSURES DURING ASPHALT PAVING OPERATIONS

at

Blaw-Knox Construction Equipment Corporation
Mattoon, Illinois

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DISCLAIMER

EXECUTIVE SUMMARY

On July 5-7, 1995, researchers from the National Institute for Occupational Safety and Health (NIOSH) evaluated prototype engineering controls designed for the control of fugitive asphalt emissions during asphalt paving The Blaw-Knox engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH researchers are conducting the research through an interagency agreement with DOT's Federal Highway Administration Additionally, the National Asphalt Pavement Association is playing a critical role in coordinating the paving manufacturers' and paving contractors' voluntary participation in the study

The study consists of two major phases During the primary phase, NIOSH researchers visit each participating manufacturer and evaluate their engineering control designs under managed environmental conditions The indoor evaluation uses tracer gas analysis techniques to both quantify the control's exhaust volume and determine the capture efficiency Results from the indoor evaluations provided equipment manufacturers with the necessary information to maximize engineering control performance prior to the second phase of the study, performance evaluation of the prototype engineering controls under "real-life" paving conditions The scope of this report is limited to the Blaw-Knox phase one evaluation

The Blaw-Knox phase one evaluation studied the performance of a single engineering control design The prototype control was installed and evaluated on a Blaw-Knox Model PF-5510 asphalt paving machine The control design consisted of a long hood mounted above the auger and against the rear of the tractor The control design included a clear plastic cover extending from the rear of the exhaust hood back to the screed, thus covering the top of the auger area A duct connected the hood to the engine air intake In this manner, the tractor engine's air intake demand dictated the volume of air mechanically exhausted through the engineering control The control system exhaust volume was approximately 280 cubic feet per minute at a corresponding engine speed near 2100 revolutions per minute (RPM) The average indoor capture efficiency was approximately 25 percent The average outdoor capture efficiency varied according to paver orientation Evaluations revealed an average capture efficiency of less than 1 percent when the paver front faced into the wind or when the paver was oriented perpendicular to the wind flow When the paver front faced away from the wind, evaluations revealed an average capture efficiency of 6 percent In addition to the capture efficiency reductions, the outdoor efficiency results showed increased variation in capture efficiency as wind gusts hampered the control's ability to consistently capture the surrogate contaminant

Recommendations to Blaw-Knox design engineers include (1) Modify the hood to a slot inlet, (2) Increase the level of hood enclosure to minimize the wind effect near the ends of the auger area, (3) Seal the openings between the tractor engine compartment and the auger area to avoid the unwanted discharge of engine cooling air into the auger area, and (4) Redesign and increase the volumetric handling capacity of the exhaust system in order to capture and remove asphalt fume and other auger-area contaminants before they escape into the workers' breathing zones

Since the intent of the phase one evaluations was to provide equipment manufacturers with engineering performance and design feedback, various original and imaginative approaches were developed with the knowledge that these prototypes would undergo preliminary performance testing to identify which designs showed the most merit Each manufacturer received design modification recommendations specific to their prototypes' performance during the phase one testing Prior to finalization of this report, each manufacturer received the opportunity to identify what modifications and/or new design features were incorporated into the "final" prototype design prior to the phase two evaluations This design information for the Blaw-Knox engineering control is included, as it was received, in Appendix C of this report

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), a Federal agency located in the Centers for Disease Control and Prevention under the Department of Health and Human Services, was established by the Occupational Safety and Health Act of 1970 This legislation mandated NIOSH to conduct research and educational programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards

The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering (DPSE), has the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness Since 1976, ECTB has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique The objective of each of these studies has been to document and evaluate control techniques and to determine their effectiveness in reducing potential health hazards in an industry or at specific processes Information on effective control strategies is subsequently published and distributed throughout the affected industry and to the occupational safety and health community

BACKGROUND

On July 5-7, 1995, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of a prototype engineering control designed for the control of fugitive asphalt emissions during asphalt paving The NIOSH researchers included Leroy Mickelsen, Chemical Engineer, Ken Mead, Mechanical Engineer, and Chandra Baker, Engineering Intern, all from the NIOSH Engineering Control Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE) The DPSE researchers were assisted by Blaw-Knox staff Jack Farley, Manager of Product Support, Leland J Warren, Design Engineer, and David L James, Engineering Design Draftsman

The Blaw-Knox engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment NIOSH/DPSE researchers are conducting the research through an interagency agreement with DOT's Federal Highway Administration (FHWA) Additionally, the National Asphalt Pavement Association (NAPA) has played a critical role in coordinating the paving manufacturers' voluntary participation in the study The study consisted of two major phases During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their engineering control designs under managed environmental conditions [General protocols for the indoor evaluations are located in Appendix A Minor deviations from these protocols may sometimes occur depending upon available time, prototype design, equipment performance, and available facilities] Results from the phase one evaluations were provided to the equipment manufacturers along with design change recommendations to maximize engineering control performance prior to the phase two evaluations The second phase evaluations, which began in mid-1996, include a performance evaluation of the prototype engineering controls under "real-life" conditions at an actual paving site The results from the Blaw-Knox phase two evaluation will be published in a separate report

DESIGN REQUIREMENTS

When designing a ventilation control, the designer must apportion the initial design criteria among three underlying considerations, the level of enclosure, the hood design, and the available control ventilation When possible, an ideal approach is to maximize the level of enclosure in order to contain the contaminant emissions With a total or near-total enclosure approach, hood design is less critical, and the required volume of control ventilation is reduced Many times, worker access or other process requirements limit the amount of enclosure allowed Under these constraints, the designer must compromise on the level of enclosure and expend increased attention to the hood design and control ventilation parameters

In the absence of a totally enclosed system, the hood design plays a critical role in determining a ventilation control's capture efficiency Given a specified exhaust flow rate, the hood shape and configuration affect the ventilation control's ability to capture the contaminant, pull it into the hood, and direct it toward the exhaust duct A well-engineered hood design strives to achieve a uniform velocity profile across the open hood face When good hood design is combined with proper enclosure techniques, cross-drafts and other airflow disturbances have less of an impact on the ventilation control's capture efficiency

In addition to process enclosure and hood design, a third area of consideration when designing a ventilation control, is the amount of ventilation air (volumetric flow and/or velocity) required to capture the contaminant and remove it from the working area For most work processes, the contaminant must be "captured" and directed into the contaminant removal system For ventilation controls, this is achieved with a moving air stream The velocity of the moving air stream is often referred to as the capture velocity. In order to maintain a protected environment, the designed capture velocity must be sufficient to overcome process-inherent contaminant velocities, convective currents, cross-drafts, or other potential sources of airflow interference

The minimum required exhaust flow rate (Q) is easily calculated by inputting the desired capture velocity and process geometry information into the design equations specific to the selected hood design Combining Q with the calculated pressure losses within the exhaust system allows the designer to appropriately select the system's exhaust fan

For most ventilation controls, including the asphalt paving controls project, these three fundamentals, process enclosure, hood design, and capture velocity are interdependent A design which lacks process enclosure can overcome this shortcoming with good hood design and increased air flow Alternatively, lower capture velocities may be adequate if increased enclosure and proper hood design techniques are followed. Additional information on designing ventilation controls can be found in the American Conference of Governmental Industrial Hygienists' (ACGIH) ***"INDUSTRIAL VENTILATION: A Manual of Recommended Practice***" [ACGIH, 6500 Glenway Avenue, Building D-7, Cincinnati, Ohio 45211]

EVALUATION PROCEDURE

The Blaw-Knox engineering control design was evaluated in a large bay area within a separate research building at the manufacturing plant The paver was parked with the screed and rear half of the tractor positioned in the bay area (referred to as the testing area) and the front half of the tractor with the engine exhaust pipe positioned outside the building An overhead door separated the two areas The overhead door was lowered to rest on top of the tractor and the remaining doorway openings around the tractor were sealed to isolate the front and rear halves of the paver During each test run, the engine exhaust (which also contained the engineering control's exhaust) was discharged to the outside of the building This setup proved very effective at preventing the engine exhaust and the captured surrogate contaminants from reentering the testing area

A theatrical smoke generator produced smoke as a surrogate contaminant that was subsequently discharged through a perforated distribution tube The tube placement traversed the width of the auger area between the tractor and the screed and rested on the ground under the augers Initially, the smoke was used to observe airflow patterns around the paver and to observe capture by the control systems (The general smoke test protocol is in Appendix A) This test also helped to identify failures in the integrity of the barrier separating the front and rear portions of the paver After sealing leaks within this barrier, smoke was again released to identify airflow patterns within the test area and to visually observe the control system's performances

The second method of evaluation was the tracer gas evaluation This evaluation was designed to (1) Calculate the total volumetric exhaust flow of each hood design, (2) Evaluate each hood's effectiveness in controlling and capturing a surrogate contaminant under the "controlled" indoor scenario Sulfur hexafluoride (SF_6) was the selected tracer gas At the concentrations generated for these evaluations, SF_6 behaves as a non-toxic, surrogate contaminant which follows the air currents of the ambient air in which it is released Since SF_6 is not naturally found within ambient environments, it is an excellent tracer gas for studying ventilation system characteristics The general protocol for the tracer gas evaluation is in Appendix A

A photo-acoustic infra-red detector (Bruel & Kjaer Model 1302) was calibrated in the NIOSH laboratories prior to the evaluation. Known amounts of reagent grade SF_6 were injected into 12-liter Milar sampling bags and diluted with nitrogen to predetermined concentrations. Five concentrations ranging from 2 to 100 parts per million (ppm) SF_6/nitrogen were generated. A curve was fit to the data and used to convert detector response to SF_6 concentrations. Calibration data are in Appendix B.

To quantify exhaust flow rate, the tracer gas discharge tubes were placed directly into the exhaust ducts of the engineering control. A known volumetric flow rate of SF_6 was released into the duct(s) and the analytical instrument measured the concentration of SF_6 in the control system's exhaust. Measurements were taken downstream of the exhaust fan to allow for thorough mixing of the exhaust air stream. The exhaust flow rate was calculated using the following equation

$$Q_{(exh)} = \frac{Q_{(SF_6)}}{C^{*}_{(SF_6)}} \times 10^6$$ **Equation 1**

where $Q_{(exh)}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

$C^{*}_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust. And the * indicates 100% capture of the released SF_6

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28.3.]

To quantify capture efficiency, we released the SF_6 through distribution plenums. Each discharge hose fed from the SF_6 regulator, through a mass flow controller and into a T-shaped distribution plenum. Each plenum was approximately 4' wide and designed to release the SF_6 evenly throughout its width. During the capture efficiency test, we placed the discharge plenums within the auger area between the paving tractor and the screed. A known quantity of SF_6 slowly discharged through the plenums into the auger area. A direct-reading analytical instrument measured the concentration of the tracer gas in the exhaust on the discharge side of the control. The capture efficiency was calculated using the following equation

$$\eta = 100 \times \frac{\dfrac{C_{(SF_6)} \times Q_{(exh)}}{10^6}}{Q_{(SF_6)}}$$ **Equation 2A**

where η = capture efficiency

$C_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust

$Q_{(exh)}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28 3]

NOTE When the flow rate of SF_6 [$Q_{(SF6)}$] used to determine the engineering control's capture efficiency is the same as that used to quantify the exhaust flow rate, equation 2A may be simplified to

where the definitions for $C^*_{(SF6)}$, η, and $C_{(SF6)}$ remain the same as in equations 1 and 2A

$$\eta = \frac{C_{(SF_6)}}{C^*_{(SF_6)}} \times 100 \qquad \text{Equation 2B}$$

Exhaust flow rate experiments were conducted by monitoring the exhaust airstream before it reached the engine air filter Once the exhaust flow rates ($Q_{(exh)}$) were known, the SF_6 was distributed into the auger region for the capture efficiency (η) evaluations Both flow rate and capture efficiency tests were repeated The paver was shut down between trials The airflow rate of the control system was partially governed by the paver idle speed which may have changed slightly between trials

In addition to the indoor evaluation, an outdoor evaluation was completed with the paver positioned in prescribed stationary orientations The outdoor stationary evaluation provided feedback on the sufficiency of the engineering control's hood enclosure for performance in an outdoor environment

EQUIPMENT

(See Appendix A)

ENGINEERING CONTROL DESIGN DESCRIPTION

The Blaw-Knox engineering control prototype consisted of a large hood mounted on the back of the tractor and extending over the augers A 6-inch duct connected the hood to the engine air intake filter The engine air intake acted as the control system fan, providing the only source of mechanical air movement for the control system

The hood measured approximately 108" long and 7" wide at the inlet The plenum tapered to 36" long and 3" wide at the top of the 14-inch tall plenum body From that point, the hood tapered to a 6-inch diameter transition for connection to the exhaust duct Clear plastic connected the edge of the hood to the front of the screed, totally enclosing the top of the auger area A small amount of clear plastic was also extended to each side of the auger area but only covered a small portion of the sides

DATA RESULTS

Smoke Evaluations

The smoke test evaluation provided only qualitative information The initial smoke tests revealed openings in the barrier between the testing and exhaust areas After resealing the separating barrier, smoke was re-released to identify airflow patterns within the test area and to visually observe the control system's performance This information assisted the researchers in preparing the test area for the quantitative tracer gas evaluation

During the indoor evaluation, an additional use for the smoke generator was created when cooling air for the tractor's engine was suspected of entering the auger area at high velocities and disrupting contaminant capture To test this suspicion, smoke from the smoke generator was discharged into the engine's cooling air intake Subsequently, some of this smoke was observed turbulently entering the auger area via openings in the rear-wall of the engine compartment

Tracer Gas Evaluation

(A copy of the tracer gas evaluation data files and associated calculations are included in Appendix B)

Indoor Evaluations

The prototype hood configuration was evaluated under the semi-controlled conditions described above Exhaust flow experiments were repeated using different SF_6 flow rates ($Q_{(SF6)}$) to increase accuracy Since building pressure fluctuations and air currents from moving people or equipment could momentarily disrupt the control's airflow characteristics, the results are reported in terms of an average and a range

TABLE I. INDOOR TRIALS, EXHAUST FLOW RATES

	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)	$Q_{(exh)}$ (Average)
Exhaust, Run 1a*	0 34 lpm	229 - 240 cfm	232 cfm
Exhaust, Run 1b	0 64 lpm	235 - 256 cfm	242 cfm
Exhaust, Run 2a	0 34 lpm	211 - 217 cfm	214 cfm
Exhaust, Run 2b	0 64 lpm	252 - 264 cfm	256 cfm

* The annotations "a" and "b" are for different SF_6 flow rates during the same test run

TABLE II. INDOOR TRIALS, CAPTURE EFFICIENCY

	$Q_{(exh)}$	η (Range)	η (Average)
Capture Eff Run 1	237 cfm	17 - 34 %	27 %
Capture Eff Run 2	235 cfm	17 - 37 %	24 %

Outdoor Evaluations

The outdoor evaluation occurred in an open parking area Four paver orientations were evaluated A portable weather station mounted on top of the paver recorded a northwest wind gusting from 5 to 15 miles per hour (mph) throughout the outdoor evaluation Paver orientations during testing included the paver front pointing toward the wind for two tests, paver sides toward the wind for three tests, and paver rear toward the wind for one test

TABLE III. OUTDOOR TRIALS (FRONT OF PAVER FACING THE WIND = ZERO DEGREES)

Orientation/ Run	$Q_{(SF6)}$	$Q_{(exh)}$ (Range)*	$Q_{(exh)}$ (Average)*	η(Range)	η(Average)
0°, Run 1a	0 34 lpm	275 - 283 cfm	278 cfm	0 6 - 1 3 %	0 8 %
0°, Run 1b	0 64	258 - 266	262	0 4 - 4 3†	1 5†
0°, Run 2a	0 34	285 - 297	292	0 2 - 3 3	0 7
0°, Run 2b	0 64	283 - 295	288		
90°, Run 1a◊	0 34	282 -289	285	0 2 - 0 7	0 5
90°, Run 1b	0 64	271 - 277	272		
0°, Run 2	0 34	285 -292	288	0 3 - 0 7	0 4
180°, Run 1a	0 34	271 - 288	280	4 6 - 7 3	5 7
180°, Run 1b	0 64	261 - 276	271		
70°, Run 1a	0 34	269 - 280	273	0 3 - 1 3	0 6
270°, Run 1b	0 64	271 - 277	275		

Q = Airflow rate

η = Capture efficiency

* Airflow rate of the control system is governed by the paver engine speed. This value may fluctuate slightly based upon changes in the paver engine's idle speed and temperature

◊ The annotations "a" and "b" are for different SF_6 flow rates during the same test run

† After run 1a, cardboard was placed in the slat-conveyor blast gate to block the wind

DATA ANALYSIS

Test results from the Blaw-Knox engineering control evaluation show that the minimal amount of airflow induced by the engine air intake results in capture efficiency of about 25 percent when tested in the semi-controlled indoor environment During the outdoor stationary tests, with wind gusts ranging from 5 to 15 mph, the prototype control was unable to remove a significant amount of the tracer gas (surrogate asphalt fume) Test results show that the system captured less than 1 percent of the tracer gas when either the front of the paver faced into the wind or when either side of the paver faced the wind The prototype control captured 5 7 percent of the tracer gas when the rear of the paver faced into the wind

Achieving a high average capture efficiency is only part of the ventilation control design approach Another consideration is the control's ability to maintain high capture efficiencies without performance levels fluctuating over a wide range Each excursion into the poor capture efficiency range represents an opportunity for contaminant to escape into a worker's breathing zone Empirically, the performance can be evaluated by comparing the sampling data coefficients of variation (CV)

$$CV = \frac{Standard\ deviation}{Mean} X\ 100$$

Controls with smaller CV's were less subject to outside interferences and maintained more consistent capture efficiencies The calculated CV's for both exhaust flow rate and capture efficiency evaluations are shown in Appendix B

CONCLUSIONS AND RECOMMENDATIONS

Based on the evaluation results, the Blaw-Knox control prototype tested during the laboratory evaluation will not significantly reduce worker exposure General recommendations for further improvements to the prototype design include

Ventilation Exhaust Volume

The ACGIH Industrial Ventilation Manual provides guidance to facilitate the selection of minimum capture velocities Additionally, NIOSH can assist in selecting a capture velocity based upon your intended control design At a minimum, given the physical properties of the asphalt fume, the vapor contaminants, and the process by which they are generated, we recommend a minimum design capture velocity of 100 feet per minute (fpm) throughout the entire auger area This recommendation assumes very good enclosure to minimize wind interference during paving operations Based upon the selected hood design and the dimensions of the auger area, this velocity will be incorporated into the design calculations to determine a minimum exhaust flow rate requirement There is some concern regarding convective currents and the generated volume of rising air induced above the hot paving process However, adequate process enclosure plus an appropriately selected capture velocity will produce a sufficient exhaust flow rate to control and remove this convective exhaust volume Additional information on controlling contaminants from hot processes may also be found in the ACGIH Ventilation Manual

Exhaust System Design

The evaluated exhaust system (engine air intake) was incompatible with the exhaust requirements of a properly operating ventilation control It may be best to redesign the engineering control exhaust independent of the engine air intake If it is desirable to use the engine's air intake to process some of the ventilation control's exhaust air, additional exhaust capacity will be necessary to create a engineering control design capable of creating a significant reduction in asphalt fume exposures Regardless of the selected exhaust route(s), it should be compatible with the volume and static pressure limitations of the exhaust fans, and the exhaust should exit the system away from the workers' breathing zones

Enclosure

In general, the prototype control design maintained good enclosure over the width of the auger Blaw-Knox's use of a clear plastic to connect the hood to the screed should aid in user acceptance of the control so long as the visibility remains unimpaired Additional enclosure efforts, especially above the ends of the auger and the screed extension areas, could increase capture efficiency, increase resistance to cross-draft disturbances and further reduce worker exposures

Engine Cooling Air

During the laboratory evaluation, some of the airflow generated by the tractor engine's cooling fan was observed discharging into the auger area through openings in the rear wall of the engine compartment This high velocity disruption dramatically reduced the control effect provided by the control system's capture velocity To avoid the unwanted discharge of engine cooling air into the auger area, minimize and seal the openings between the tractor engine compartment and the auger area

Hood Design

The evaluated hood design should perform well if adequately matched with a sufficient exhaust flow capacity and a compatible auger-area enclosure An alternative design which evenly distributed exhaust air flow across the hood's face area would improve inlet flow distribution and increase protection across the full length of the augers The evaluated design would be less-effective at locations away from the center of the hood An evenly distributed intake can be achieved through the use of a slot hood or similar plenum-type exhaust hood configuration

ACKNOWLEDGMENTS

We would like to thank the Blaw-Knox management and staff for their gracious hospitality and assistance during our visit to the Blaw-Knox facility Their commitment to the design and implementation of engineering controls to reduce occupational exposures is an admirable pledge

APPENDIX A

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

PHASE ONE (LABORATORY) EVALUATION PROTOCOL

PURPOSE To evaluate the efficiency of ventilation engineering controls used on highway-class hot mix asphalt (HMA) pavers in an indoor stationary environment

SCOPE OF USE This test procedure was developed to aid the HMA industry in the development and evaluation of prototype ventilation engineering controls with an ultimate goal of reducing worker exposures to asphalt fumes This test procedure is a first step in evaluating the capture efficiency of paver ventilation systems and is conducted in a controlled environment The test is not meant to simulate actual paving conditions The data generated using this test procedure have not been correlated to exposure reductions during actual paving operations

For the laboratory evaluation, we will conduct a two-part experiment where the surrogate "contaminant" is injected into the auger region behind the tractor and in front of the screed For part A of the evaluation, smoke from a smoke generator is the surrogate contaminant For part B, the surrogate contaminant is sulfur hexafluoride, an inert and relatively safe (when properly used) gas, commonly used in tracer gas studies

SAFETY In addition to following the safety procedures established by the host facility, the following concerns should be addressed at each testing site

1 The discharge of the smoke generating equipment can be hot and should not be handled with unprotected hands
2 The host may want to contact building and local fire officials in order that the smoke generators do not set off fire sprinklers or create a false alarm
3 In higher concentrations, smoke generated from the smoke generators may act as an irritant Direct inhalation of smoke from the smoke generators should be avoided
4 All compressed gas cylinders should be transported, handled, and stored in accordance with the safety recommendations of the Compressed Gas Association
5 The Threshold Limit Value for sulfur hexafluoride is 1000 ppm While the generated concentrations will be below this level, the concentration in the cylinder is near 100 percent For this reason, the compressed cylinder will be maintained outdoors whenever possible Should a regulator malfunction or some other major accidental release occur, observers should stand back and let the tank pressure come to equilibrium with the ambient environment

Laboratory Setup The following laboratory setup description is based on our understanding of the facilities available at the asphalt paving manufacturing facilities participating in the study The laboratory evaluation protocol may vary slightly from location to location depending upon the available facilities

Paver Position The paving tractor, with screed attached, will be parked underneath an overhead garage door such that both the tractor exhaust and the exhaust from the engineering controls exits into the ambient air The garage door will be lowered to rest on top of the tractor and plastic or an alternative barrier will be applied around the perimeter of the tractor to seal the remainder of the garage door opening

Laboratory Ventilation Exhaust For this evaluation, smoke generated from Rosco Smoke Generators (Rosco, Port Chester, NY) is released into a perforated plenum and dispersed in a quasi-uniform distribution along the length of the augers Due to interferences created by the auger's gear box, this evaluation may require a separate smoke generator and distribution plenum on each side of the auger region Releasing theatrical smoke as a surrogate contaminant within the auger region provides excellent qualitative information concerning the engineering control's performance Areas of diminished control performance are easily determined and minor modifications can be incorporated into the design prior to quantifying the control performance Additionally, the theatrical smoke helps to verify the barrier integrity separating the front and rear halves of the asphalt paver A video camera will be used to record the evaluation The sequence from a typical test run is outlined below

1 Position paving equipment within door opening and lower overhead door
2 Seal the remaining door opening around the tractor
3 Place the smoke distribution tube(s) directly underneath the auger
4 Connect the smoke generator(s) to the distribution tube(s)
5 Activate video camera, the engineering controls and the smoke generator(s)
6 Inspect the separating barrier for integrity failures and correct as required
7 Inspect the engineering control and exhaust system for unintended leaks
8 De-activate the engineering controls for comparison purposes
9 De-activate smoke generators and wait for smoke levels to subside
10 End the smoke test evaluation

Evaluation Part B (Tracer Gas) The tracer gas test is designed to (1) calculate the total exhaust flow rate of the paver ventilation control system, and (2) evaluate the effectiveness in capturing and controlling a surrogate contaminant under a "controlled" indoor conditions SF_6 will be used as the surrogate contaminant

Quantify Exhaust Volume: To determine the total exhaust flow rate of the engineering control, a known quantity of sulfur hexafluoride (SF_6) is released directly into the engineering control's exhaust hood, thus creating a 100 percent capture condition The SF_6 release is controlled by two Tylan Mass Flow controllers (Tylan, Inc , San Diego, CA) Initially, the test will be performed using a single flow controller calibrated at 0 35 lpm A hole drilled into the engineering control's exhaust duct allows access for a multi-point monitoring wand into the exhaust stream The monitoring wand is oriented such that the perforations are perpendicular to the moving air stream A sample tube connects the wand to a Bruel & Kjaer (B&K) Model 1302 Photo acoustic Infra-red Multi-gas Monitor (California Analytical Instruments, Inc , Orange, CA) positioned on the exterior side of the overhead door The gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream The B&K 1302 will be programmed to repeat this analysis approximately once every 30 seconds Monitoring will continue until approximate steady-state conditions are achieved The mean concentration of SF_6

measured in the exhaust stream will be used to calculate the total exhaust flow rate of the engineering control. The equation for determining the exhaust flow rate is

$$Q_{(exh)} = \frac{Q_{(SF_6)}}{C^*_{(SF_6)}} \times 10^6$$ **Equation 1**

where $Q_{(exh)}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

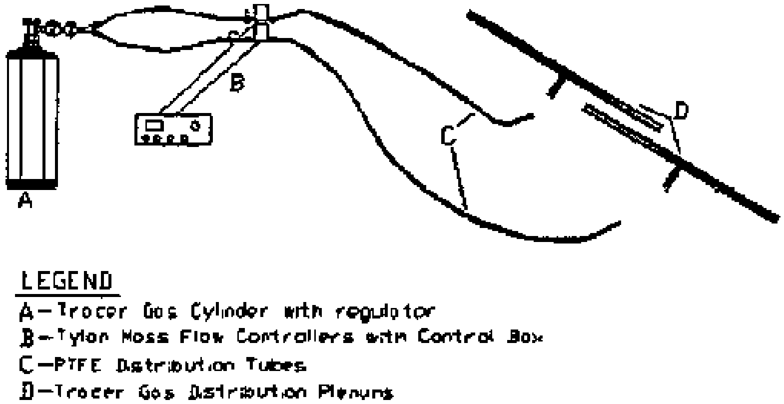
$C^*_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28.3.]

In order to increase accuracy, the exhaust flow rate will be calculated a second time using two mass flow controllers, each calibrated at approximately 0.35 lpm of SF_6. Sufficient time will be allowed between all test runs to allow area concentrations to decay below 0.1 ppm before starting subsequent test runs.

<u>Quantitative Capture Efficiency</u>: The test procedure to determine capture efficiency is slightly different than the exhaust volume procedure. The mass flow controllers will each be calibrated for a flow rate approximating 0.35 liters per minute (lpm) of 99.8 percent SF_6. The discharge tubes from the mass flow controllers will each feed a separate distribution plenum, one per side, within the paver's auger area. The distribution plenums are designed to distribute the SF_6 in a uniform pattern along the length of the auger area. (See Figure 1.) The B&K multi-gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream until approximate steady-state conditions develop. Once this occurs, the SF_6 source will be discontinued and the decay concentration of SF_6 within the exhaust stream will be monitored to indicate the extent in which general area concentrations of non-captured SF_6 contributed to the concentration measured in the exhaust stream.

FIGURE 1



A capture efficiency can be calculated for the control using the following equation

$$\eta = 100 \times \frac{\frac{C_{(SF_6)} \times Q_{(exh)}}{10^6}}{Q_{(SF_6)}} \qquad \text{Equation 2A}$$

where η = capture efficiency

$C_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust

$Q_{(exh)}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28 3]

NOTE When the flow rate of SF_6 [$Q_{(SF6)}$] used to determine the engineering control's capture efficiency is the same as that used to quantify the exhaust flow rate, equation 2A may be simplified to

$$\eta = \frac{C_{(SF_6)}}{C^{*}_{(SF_6)}} \times 100 \qquad \text{Equation 2B}$$

where the definitions for $C^*_{(SF6)}$, η, and $C_{(SF6)}$ remain the same as in equations 1 and 2A

The sequence from a typical test run is outlined below

1 Position paving equipment and seal openings as outlined above
2 Calibrate (outdoors) both mass flow meters at approximately 0 35 lpm of SF_6
3 Drill an access hole in the engineering control's exhaust duct on the outdoor side of the overhead door and position the sampling wand into the hole
4 While maintaining the SF_6 tanks outdoors, run the discharge hoses from the mass flow meters to well-within the exhaust hood(s) to create 100 percent capture conditions
5 With the engineering controls activated, begin monitoring with the B&K 1302 to determine background interference levels
6 Initiate flow of SF_6 through a single mass flow meter
7 Continue monitoring with the B&K for five minutes or until three repetitive readings are recorded
8 Deactivate flow of the SF_6 and calculate exhaust flow rate using the calculation identified above
9 Repeat steps #2 through #8 using both mass flow controllers
10 Allow engineering control exhaust system to continue running until SF_6 has ceased leaking from the discharge hoses then remove the hoses from the hoods
11 End the exhaust flow rate test
12 Locate an SF_6 distribution plenum on each side of the auger area and connect each plenum to the discharge hose of a mass flow meter
13 Initiate B&K monitoring to establish background interference levels until levels reach 0 1 ppm or below
14 Initiate SF_6 flow through the mass flow meters and monitor with the B&K until approximate steady state conditions appear
15 Once steady state is achieved, discontinue SF_6 flow and quickly remove the distribution plenums and discharge hoses from the auger area
16 Continue monitoring with the B&K to determine the general area concentration of SF_6 which escaped auger area into the laboratory area
17 Discontinue B&K monitoring when concentration decay is complete
18 Calculate the capture efficiency
19 Repeat steps 11 - 17 as time permits

APPENDIX B

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

TRACER GAS EVALUATION RESULTS

B&K DATA FILES AND CALCULATION RESULTS

APPENDIX C

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

BLAW-KNOX PROTOTYPE DESIGN MODIFICATIONS PRIOR TO PHASE TWO FIELD EVALUATIONS

Blaw Knox	**Summary from data sheets**					
Inside garage, "no wind"						
	Ventilation flow tylan #2 (cfm)	Ventilation flow two tylans (cfm)	Capture efficiency %	Ventilation flow tylan #2 (cfm)	Ventilation flow two tylans (cfm)	Capture efficiency %
Mean	232	242	27	214	256	24
Min	229	235	17	211	252	17
Max	240	256	34	217	264	37
CV	2	3	25	1	1.5	26
Outside with paver front to the wind, 0 degrees with north = zero degrees.						
	Ventilation flow tylan #2 (cfm)	Ventilation flow two tylans (cfm)	Capture efficiency %*	Ventilation flow tylan #2 (cfm)	Ventilation flow two tylans (cfm)	Capture efficiency %
Mean	278	262	0.81 (1.52)	292	288	0.73
Min	275	258	0.58 (0.42)	285	283	0.16
Max	283	266	1.29 (4.33)	297	295	3.27
CV	1.2	1.1	39 (81)	1.7	1.3	116
Outside with paver side to the wind, 90 degrees with north = zero degrees						
	Ventilation flow tylan #2 (cfm)	Ventilation flow two tylans (cfm)	Capture efficiency %	Ventilation flow tylan #2 (cfm)	Ventilation flow two tylans (cfm)	Capture efficiency %
Mean	285	272	0.47	288	-	0.42
Min	282	271	0.22	285	-	0.25
Max	289	277	0.74	292	-	0.73
CV	0.7	1	40	0.8	-	39
Outside with paver rear to the wind, 180 degrees with north = zero degrees.						
	Ventilation flow tylan #2 (cfm)	Ventilation flow two tylans (cfm)	Capture efficiency %	Ventilation flow tylan #2 (cfm)		
Mean	280	271	5.67	272		
Min	271	261	4.55	256		
Max	288	276	7.3	284		
CV	2.1	2	15	4.9		
Outside with paver side to the wind, 270 degrees with north = zero degrees.						
	Ventilation flow tylan #2 (cfm)	Ventilation flow two tylans (cfm)	Capture efficiency %			
Mean	273	275	0.61			
Min	269	271	0.29			
Max	280	277	1.26			
CV	1.2	1	43			
* Cardboard placed in slat-convayer blast gate to block off wind						

Blaw Knox Inside Garage Measurements, Engine outside

1302 Measurement Data 17886 11/2803 - 7/5/95 19 11 Page 1
1302 Settings
Compensate for Water Vapor Interference NO
Compensate for Cross Interference NO
Sample Continuously YES
Preset Monitoring Period NO
Measure
Gas A Sulfur hexafluoride YES
Water Vapour NO
Sampling Tube Length 15 0 ft
Air Pressure ressure 760 0 mmHg
Normalization Temperature 80 0 F
Start Time 1995-07-05 17 01
Stop Time 1995-07-05 19 06
Results Not Averaged
Number of Events Marked 13
Number of Recorded Samples 199

	Alarm Limit	Max	Mean	Min	Std Dev
Gas A	______	237	15 2 E+00	5 49E-02	2 87E+01

Samp No	Time hh mm ss	Gas A ppm	Calibration Correction				
1	17 01 47	6 64E-02	0 077934	**Area background**			
2	17 02 30	6 20E-02	0 072769				
3	17 03 05	6 65E-02	0 078051			**SF6 flow**	
4	17 03 40	5 65E-02	0 066314			tylan #2	
5	17 04 16	5 98E-02	0 070187			0 3388	lpm
6	17 05 02	6 05E-02	0 071009			Both tylans	
7	17 05 37	6 61E-02	0 077582			0 6374	lpm
8	17 06 13	6 11E-02	0 071713				
9	17 06 48	5 91E-02	0 069366				
10	17 07 23	6 17E-02	0 072417				
11	17 07 59	6 10E-02	0 071596				
12	17 08 34	5 92E-02	0 069483				
13	17 09 09	6 13E-02	0 071948				
14	17 09 45	5 96E-02	0 069953				
15	17 10 20	5 89E-02	0 069131				
16	17 10 56	5 49E-02	0 064436				
17	17 11 31	6 09E-02	0 071478	Avg	0 071231		
18	17 12 06	5 68E-02	0 066666	Std Dev	0 003662		
19	17 12 42	6 08E-02	0 071361	CV	5 14%		
	17 13 17	User Event		Number	1		
20	17 13 17	3 58E+00	4 201846	In duct			
21	17 13 55	4 43E+01	51 99491	**Tylan #2 only**			
22	17 15 04	4 45E+01	52 22965	**100% capture**			
23	17 15 39	4 24E+01	49 76488	Avg	51 5489	232 0057	Mean flow
24	17 16 15	4 41E+01	51 76017	Std Dev	1 011018	228 9818	Min
25	17 16 50	4 43E+01	51 99491	CV	1 96%	240 3229	Max
	17 17 26	User Event		Number	2		
26	17 17 26	4 61E+01	54 10757	**In duct w/ 90 degree**			
27	17 18 01	4 62E+01	54 22494	**change in sample probe**			

28	17 18 37	4 57E+01	53 63809	**Tylan #2 only**			
29	17 19 12	4 42E+01	51 87754	**100% capture**			
30	17 19 47	4 62E+01	54 22494	Avg	53 49138	223 5807	Mean flow
31	17 20 23	4 44E+01	52 11228	Std Dev	1 018871	219 1331	Min
32	17 20 58	4 53E+01	53 16861	CV	1 90%	230 536	Max
33	17 21 34	4 65E+01	54 57705				
	17 21 34	User Event		Number	3		
34	17 22 09	8 14E+01	95 53918	**Both tylans on**			
35	17 22 45	8 17E+01	95 89129	**100% capture**			
36	17 23 20	7 75E+01	90 96175				
37	17 23 56	7 97E+01	93 54389	Avg	93 07441	241 7444	Mean flow
38	17 24 50	8 00E+01	93 896	Std Dev	2 744217	234 643	Min
39	17 25 26	7 98E+01	93 66126	CV	2 95%	255 6044	Max
40	17 26 01	7 50E+01	88 0275				
	17 26 01	User Event		Number	4		
41	17 26 37	8 07E+00	9 471759	**SF6 off**			
42	17 27 15	6 92E+00	8 122004	**SF6 tubing placed in**			
43	17 27 50	6 91E+00	8 110267	**distribution tubes**			
44	17 28 25	6 02E+00	7 065674				
45	17 29 01	4 48E+00	5 258176				
46	17 29 36	4 77E+00	5 598549				
47	17 30 12	4 03E+00	4 730011				
48	17 30 47	2 52E+00	2 957724				
49	17 31 23	3 15E+00	3 697155				
50	17 31 58	4 44E+00	5 211228				
51	17 32 33	2 41E+00	2 828617				
52	17 33 09	2 28E+00	2 676036				
53	17 33 46	5 84E-01	0 685441				
54	17 34 22	2 17E-01	0 254693				
55	17 35 08	1 73E-01	0 20305				
56	17 35 43	1 77E-01	0 207745				
57	17 36 19	1 43E-01	0 167839				
58	17 36 54	1 11E-01	0 130281	Avg	0 137792		
59	17 37 29	1 24E-01	0 145539	Std Dev	0 019225		
60	17 38 05	1 05E-01	0 123239	CV	13 95%		
61	17 38 40	1 04E-01	0 122065				
	17 38 40	User Event		Number	5		
62	17 39 15	3 83E-01	0 449527	**Background in building**			
63	17 39 50	4 07E-01	0 477696	**Probe above screed**			
64	17 40 26	3 16E-01	0 370889				
65	17 41 01	3 27E-01	0 3838				
66	17 41 37	2 85E-01	0 334505				
67	17 42 12	4 19E-01	0 49178				
68	17 42 48	3 58E-01	0 420185				
69	17 43 24	3 54E-01	0 41549				
70	17 43 59	3 65E-01	0 428401				
71	17 45 06	2 96E-01	0 347415				
72	17 45 41	3 01E-01	0 353284				
73	17 46 16	2 56E-01	0 300467				
74	17 46 52	2 55E-01	0 299294				
75	17 47 27	2 54E-01	0 29812				
76	17 48 03	2 51E-01	0 294599				

77	17 48 38	1 93E-01	0 226524					
78	17 49 13	1 40E-01	0 164318					
79	17 49 49	1 54E-01	0 18075					
80	17 50 24	1 29E-01	0 151407					
81	17 51 00	9 32E-02	0 109389					
82	17 51 35	9 12E-02	0 107041					
83	17 52 10	9 83E-02	0 115375	Avg	0 289733			
84	17 52 46	9 48E-02	0 111267	Std Dev	0 129523			
	17 55 56	User Event		Number	6			
85	17 55 20	6 04E-02	0 070891	**Probe into duct**				
86	17 55 56	6 83E-02	0 080164	Avg	0 075547			
87	17 56 50	6 44E-02	0 075586	Std Dev	0 004636			
	17 57 26	User Event		Number	7			
88	17 57 26	1 78E+00	2 089186	**Both tylans on**				
89	17 58 01	1 12E+01	13 14544	**SF6 distribution**				
90	17 58 39	2 64E+01	30 98568					
91	17 59 14	1 82E+01	21 36134					
92	17 59 50	1 89E+01	22 18293					
93	18 00 25	1 34E+01	15 72758					
94	18 01 01	2 69E+01	31 57253					
95	18 01 36	1 52E+01	17 84024					
96	18 02 12	1 94E+01	22 76978	Avg	24 97373	26 83%	Ave Eff	
97	18 02 47	2 60E+01	30 5162	Std Dev	6 316419	16 90%	Min Eff	
98	18 03 22	2 71E+01	31 80727	CV	25 29%	34 17%	Max Eff	
	18 04 00	User Event		Number	8			
99	18 04 00	5 84E+00	6 854408	**SF6 off**				
100	18 04 49	1 31E+00	1 537547					
101	18 05 27	3 54E-01	0 41549					
102	18 06 03	1 47E-01	0 172534					
103	18 06 38	1 12E-01	0 131454					
104	18 07 13	9 50E-02	0 111502					
105	18 07 49	9 77E-02	0 11467					
106	18 08 24	1 04E-01	0 122065					
107	18 09 00	9 24E-02	0 10845					
108	18 09 35	9 03E-02	0 105985					
109	18 10 11	9 38E-02	0 110093					
110	18 10 46	8 04E-02	0 094365					
111	18 11 21	7 62E-02	0 089436					
112	18 11 57	8 47E-02	0 099412					
113	18 12 32	7 51E-02	0 088145					
114	18 13 08	7 42E-02	0 087089					
115	18 13 43	6 96E-02	0 08169					
116	18 14 18	6 96E-02	0 08169					
117	18 15 25	6 71E-02	0 078755					
118	18 16 00	6 84E-02	0 080281	Avg	0 082941			
119	18 16 36	2 23E-01	0 261735	Std Dev	0 003795			
120	18 17 11	1 63E-01	0 191313	CV	4 58%			
	18 17 47	User Event		Number	9			
121	18 17 47	2 34E-01	0 274646	**Both tylans on**				
122	18 18 22	1 87E+01	21 94819	**SF6 distribution**				
123	18 19 01	1 60E+01	18 7792					
124	18 19 37	2 73E+01	32 04201					

125	18 20 14	2 19E+01	25 70403					
126	18 20 52	1 38E+01	16 19706					
127	18 21 28	2 92E+01	34 27204					
128	18 22 06	2 03E+01	23 82611					
129	18 22 43	1 67E+01	19 60079	Avg	22 75911	24 45%	Ave Eff	
130	18 23 19	1 27E+01	14 90599	Std Dev	6 025428	17 40%	Min Eff	
131	18 23 54	1 87E+01	21 94819	CV	26 47%	36 82%	Max Eff	
132	18 24 49	1 80E+01	21 1266					
	18 24 49	User Event		Number	10			
133	18 25 25	2 05E+00	2 406085	**SF6 off**				
134	18 26 02	1 99E+00	2 335663					
135	18 26 38	7 31E-01	0 857975					
136	18 27 13	8 62E-01	1 011729					
137	18 27 49	3 30E+00	3 87321					
138	18 28 26	1 31E+00	1 537547					
139	18 29 04	2 97E+00	3 485889					
140	18 29 42	1 53E+00	1 795761					
141	18 30 20	3 61E+00	4 237057					
142	18 30 58	3 00E+00	3 5211					
143	18 31 33	1 61E+00	1 889657					
144	18 32 11	1 61E+00	1 889657					
145	18 32 47	5 17E-01	0 606803					
146	18 33 22	1 20E+00	1 40844					
147	18 33 57	3 05E+00	3 579785					
148	18 34 46	1 45E+00	1 701865					
149	18 35 25	1 93E+00	2 265241					
150	18 36 00	2 36E+00	2 769932					
151	18 36 36	3 83E+00	4 495271					
152	18 37 14	6 52E+00	7 652524					
153	18 37 49	4 51E+00	5 293387					
154	18 38 24	3 62E+00	4 248794					
155	18 39 00	3 08E+00	3 614996					
156	18 39 35	7 66E-01	0 899054					
157	18 40 13	2 70E-01	0 316899					
158	18 40 49	1 87E-01	0 219482					
159	18 41 24	1 76E-01	0 206571					
160	18 42 00	1 70E-01	0 199529					
161	18 42 35	1 48E-01	0 173708					
162	18 43 11	1 17E-01	0 137323					
163	18 43 46	1 12E-01	0 131454					
164	18 44 22	9 12E-02	0 107041					
165	18 45 28	7 82E-02	0 091783					
166	18 46 04	7 05E-02	0 082746	Avg	0 102065			
167	18 46 39	9 81E-02	0 11514	Std Dev	0 014213			
168	18 47 15	9 68E-02	0 113614	CV	13 93%			
	18 47 51	User Event		Number	11			
169	18 47 51	2 63E-01	0 308683	**Tylan #2 only**				
170	18 48 26	4 83E+01	56 68971	**100% capture**				
171	18 49 07	4 77E+01	55 98549					
172	18 49 42	4 70E+01	55 1639					
173	18 50 17	4 77E+01	55 98549	Avg	55 93854	213 7996	Mean flow	
174	18 50 53	4 76E+01	55 86812	Std Dev	0 541685	210 9667	Min	

175	18 51 28	4 35E+01	51 05595	CV	0 97%	216 8019	Max	
	18 52 04	User Event		Number	12			
176	18 52 04	2 37E+02	278 1669	**Both tylans on**				
177	18 52 39	7 21E+01	84 62377	**100% capture**				
178	18 53 14	7 56E+01	88 73172					
179	18 53 50	7 52E+01	88 26224					
180	18 54 25	7 56E+01	88 73172					
181	18 55 20	7 54E+01	88 49698					
182	18 55 55	7 61E+01	89 31857					
183	18 56 31	7 44E+01	87 32328					
184	18 57 06	7 38E+01	86 61906	Avg	87 8045	256 2536	Mean flow	
185	18 57 41	7 57E+01	88 84909	Std Dev	1 315673	251 9098	Min	
186	18 58 17	7 27E+01	85 32799	CV	1 50%	263 691	Max	
187	18 58 52	7 36E+01	86 38432					
	18 58 52	User Event		Number	13			
188	18 59 28	3 88E-01	0 455396	**Background in room.**				
189	19 00 08	1 36E-01	0 159623					
190	19 00 43	1 27E-01	0 14906					
191	19 01 19	1 12E-01	0 131454					
192	19 01 54	1 20E-01	0 140844					
193	19 02 30	1 02E-01	0 119717					
194	19 03 05	9 87E-02	0 115844					
195	19 03 40	9 42E-02	0 110563					
196	19 04 16	8 42E-02	0 098826					
197	19 05 02	8 43E-02	0 098943	Avg	0 099483			
198	19 05 38	8 22E-02	0 096478	Std Dev	0 006705			
199	19 06 13	7 89E-02	0 092605	CV	6 74%			

Blaw Knox Inside Garage Measurements, Engine exhausted through duct

- 1302 Measurement Data ---- 1788611/2803 - 1995-07-06 17 15 - Page 1 -

1302 Settings	
Compensate for Water Vap Interference	NO
Compensate for Cross Interference	NO
Sample Continuously	YES
Pre-set Monitoring Period	NO
Measure	
Gas A Sulfur hexafluoride	YES
Water Vapour	NO
Sampling Tube Length	15 0 ft
Air Pressure	760 0 mmHg
Normalization Temperature	80 0 F
Start Time	1995-07-06 15 31
Stop Time	1995-07-06 16 21
Results Not Averaged	
Number of Event Marks	6
Number of Recorded Samples	82

	Alarm Limit	Max	Mean	Min	Std Dev
Gas A	________	71 7E+00	11 8E+00	49 9E-03	20 8E+00

Samp No	Time hh mm ss	Gas A ppm	Calibration Correction				
1	15 31 19	6 09E-02	0 071478	**Area background**			
2	15 32 02	4 99E-02	0 058568	**then in duct background**			
3	15 32 37	5 15E-02	0 060446	Avg	0 063497	**SF6 flow**	
4	15 33 13	2 93E-01	0 343894	Std Dev	0 006975	tylan #2	
5	15 33 48	2 72E-01	0 319246	CV	10 99%	0 3397	lpm
6	15 34 23	2 26E-01	0 265256			Both tylans	
	15 34 23	User Event		Number	1	0 6435	lpm
7	15 34 59	3 67E+01	43 07479	**Tylan #2 only**			
8	15 35 39	3 52E+01	41 31424	**100% capture**			
9	15 36 15	3 48E+01	40 84476				
10	15 36 50	3 53E+01	41 43161				
11	15 37 25	3 48E+01	40 84476	Avg	41 66635	287 796	Mean flow
12	15 38 01	3 60E+01	42 2532	Std Dev	0 807497	278 3858	Min
13	15 38 36	3 57E+01	41 90109	CV	1 94%	293 585	Max
	15 39 23	User Event		Number	2		
14	15 39 23	4 43E+01	51 99491	**Both tylans on**			
15	15 39 58	7 12E+01	83 56744	**100% capture**			
16	15 40 33	7 15E+01	83 91955				
17	15 41 09	7 11E+01	83 45007				
18	15 41 44	7 07E+01	82 98059	Avg	83 587	271 7594	Mean flow
19	15 42 19	7 17E+01	84 15429	Std Dev	0 409395	269 9274	Min
20	15 42 55	7 11E+01	83 45007	CV	0 49%	273 7453	Max
	15 43 30	User Event		Number	3		
21	15 43 30	7 12E+01	83 56744	Avg	1 784024		
22	15 44 06	1 52E+00	1 784024	**Moving equipment**			
	15 44 46	User Event		Number	4		
23	15 44 46	9 35E-01	1 09741	**Both tylans on**			
24	15 45 21	3 51E+00	4 119687	**SF6 distribution**			
25	15 45 59	3 41E+00	4 002317				
26	15 46 35	4 39E+00	5 152543				
27	15 47 10	4 71E+00	5 528127				
28	15 47 46	6 01E+00	7 053937				
29	15 48 21	6 68E+00	7 840316	Avg	6 208873	7 43%	Ave Eff
30	15 49 27	6 50E+00	7 62905	Std Dev	1 722479	4 79%	Min Eff
31	15 50 03	7 11E+00	8 345007	CV	27 74%	9 98%	Max Eff
	15 50 38	User Event		Number	5		

32	15 50 38	6 87E+00	8 063319	**SF6 off**		
33	15 51 14	7 83E+00	9 190071			
34	15 51 49	6 33E+00	7 429521	Avg	7 793368	
35	15 52 25	6 25E+00	7 335625	Std Dev	0 877454	
36	15 53 00	5 92E+00	6 948304	CV	11 26%	
	15 53 35	User Event		Number	6	
37	15 53 35	5 59E+00	6 560983	**In room decay rate**		
38	15 54 11	5 08E+00	5 962396			
39	15 54 46	4 92E+00	5 774604			
40	15 55 21	4 59E+00	5 387283			
41	15 55 57	4 37E+00	5 129069			
42	15 56 32	4 08E+00	4 788696			
43	15 57 08	3 78E+00	4 436586			
44	15 57 43	3 58E+00	4 201846			
45	15 58 18	3 36E+00	3 943632			
46	15 59 13	3 34E+00	3 920158			
47	15 59 49	3 11E+00	3 650207			
48	16 00 24	2 94E+00	3 450678			
49	16 00 59	2 88E+00	3 380256			
50	16 01 35	2 67E+00	3 133779			
51	16 02 10	2 62E+00	3 075094			
52	16 02 45	2 45E+00	2 875565			
53	16 03 21	2 38E+00	2 793406			
54	16 03 56	2 24E+00	2 629088			
55	16 04 32	2 20E+00	2 58214			
56	16 05 10	2 09E+00	2 453033			
57	16 05 45	2 00E+00	2 3474			
58	16 06 20	1 94E+00	2 276978			
59	16 06 56	1 85E+00	2 171345			
60	16 07 31	1 77E+00	2 077449			
61	16 08 06	1 67E+00	1 960079			
62	16 08 42	1 61E+00	1 889657			
63	16 09 28	1 52E+00	1 784024			
64	16 10 04	1 44E+00	1 690128			
65	16 10 39	1 34E+00	1 572758			
66	16 11 14	1 32E+00	1 549284			
67	16 11 50	1 24E+00	1 455388			
68	16 12 25	1 21E+00	1 420177			
69	16 13 01	1 15E+00	1 349755			
70	16 13 36	1 10E+00	1 29107			
71	16 14 11	1 06E+00	1 244122			
72	16 14 47	1 01E+00	1 185437			
73	16 15 22	9 62E-01	1 129099			
74	16 15 58	9 23E-01	1 083325			
75	16 16 33	8 94E-01	1 049288			
76	16 17 09	8 68E-01	1 018772			
77	16 17 44	8 30E-01	0 974171			
78	16 18 19	7 88E-01	0 924876			
79	16 19 26	7 37E-01	0 865017			
80	16 20 01	7 20E-01	0 845064			
81	16 20 37	6 92E-01	0 8122			
82	16 21 12	6 54E-01	0 7676			
*********	**** COM	NT *******	*******			
indoor test after some modificatins to wind (increased					90	between
engine and the rear of tractor			intended ot minimize		amount	
of engine cooling air which intefers with engineenng control in auger area						
*********	* END OF	OMMENT	*******			

Blaw Knox | **Outside, wind @ 0 degrees blowing @ front of paver, 8-10 mph**

- 1302 Measurement Data —— 1788611/2803 - 1995-07-06 12 54 - Page 1 -

1302 Settings	
Compensate for Water Vap Interference	NO
Compensate for Cross Interference	NO
Sample Continuously	YES
Pre-set Monitoring Period	NO
Measure	
Gas A Sulfur hexafluoride	YES
Water Vapour	NO
Sampling Tube Length	15 0 ft
Air Pressure	760 0 mmHg
Normalization Temperature	80 0 F
Start Time	1995-07-06 10 33
Stop Time	1995-07-06 10 54
Results Not Averaged	
Number of Event Marks	5
Number of Recorded Samples	33

	Alarm Limit	Max	Mean	Min	Std Dev
Gas A		75 1E+00	20 1E+00	56 6E-03	28 4E+00

Samp No	Time hh mm ss	Gas A ppm	Calibration Correction				
1	10 33 55	6 36E-02	0 074647	**Background**			
	10 34 38	User Event		Number	1		
2	10 34 38	5 66E-02	0 066431	In duct		**SF6 flow**	
3	10 35 13	6 09E-02	0 071478			tylan #2	
	10 35 13	User Event		Number	2	0 3397	lpm
4	10 35 49	1 89E-01	0 221829	In duct		Both tylans	
5	10 36 24	5 16E-01	0 605629	**Both tylans on**		0 6435	lpm
6	10 37 00	5 66E-01	0 664314	**SF6 distribution**			
7	10 37 35	9 54E-01	1 11971				
8	10 38 10	4 61E-01	0 541076				
9	10 38 46	7 67E-01	0 900228				
10	10 39 21	8 41E-01	0 987082	Avg	0 703046	0 81%	Ave Eff
11	10 39 56	4 29E-01	0 503517	Std Dev	0 275263	0 58%	Min Eff
12	10 40 43	2 58E-01	0 302815	CV	39 15%	1 29%	Max Eff
	10 41 18	User Event		Number	3		
13	10 41 18	7 32E-01	0 859148	**Same as above**			
14	10 41 53	3 13E-01	0 367368	**Cardboard placed in**			
15	10 42 29	1 58E+00	1 854446	**blast gates**			
16	10 43 04	4 69E-01	0 550465				
17	10 43 39	1 29E+00	1 514073				
18	10 44 15	3 19E+00	3 744103				
19	10 44 52	3 40E-01	0 399058	Avg	1 311936	1 52%	Ave Eff
20	10 45 30	1 39E+00	1 631443	Std Dev	1 063215	0 42%	Min Eff
21	10 46 05	7 56E-01	0 887317	CV	81 04%	4 33%	Max Eff
	10 46 42	User Event		Number	4		
22	10 46 42	2 22E+01	26 05614	**In duct**			
23	10 47 20	7 40E+01	86 8538	**both tylans on**			
24	10 47 58	7 51E+01	88 14487	**100% capture**			
25	10 48 33	7 38E+01	86 61906				
26	10 49 08	7 30E+01	85 6801	Avg	86 54081	262 4837	Mean flow
27	10 49 44	7 28E+01	85 44536	Std Dev	0 861193	257 707	Min
28	10 50 19	7 37E+01	86 50169	CV	1 11%	265 8488	Max
	10 51 26	User Event		Number	5		
29	10 51 26	3 72E+01	43 66164	**100% capture**			
30	10 52 01	3 71E+01	43 54427	**Tylan #2 only**			
31	10 52 37	3 61E+01	42 37057	Avg	43 14521	277 9314	Mean flow
32	10 53 12	3 65E+01	42 84005	Std Dev	0 53529	274 6441	Min
33	10 53 48	3 69E+01	43 30953	CV	1 24%	283 0127	Max

Blaw Knox **Outside, wind @ 0 degrees blowing @ front of paver, 8-10 mph**

- 1302 Measurement Data —— 1788611/2803 - 1995-07-06 13 00 - Page 1 -

1302 Settings
Compensate for Water Vap Interference NO
Compensate for Cross Interference NO
Sample Continuously YES
Pre-set Monitoring Period NO
Measure
Gas A Sulfur hexafluoride YES
Water Vapour NO
Sampling Tube Length 15 0 ft
Air Pressure 760 0 mmHg
Normalization Temperature 80 0 F
Start Time 1995-07-06 12 06
Stop Time 1995-07-06 12 24
Results Not Averaged
Number of Event Marks 3
Number of Recorded Samples 30

	Alarm Limit	Max	Mean	Min	Std Dev
Gas A	________	68 3E+00	23 5E+00	69 3E-03	28 3E+00

Samp No	Time hh mm ss	Gas A ppm	Calibration Correction				
1	12 06 31	2 27E-01	0 26643	Area background			
2	12 07 14	8 72E-02	0 102347	Avg	0 090336		
3	12 07 49	7 44E-02	0 087323	Std Dev	0 010824	**SF6 flow**	
4	12 08 24	6 93E-02	0 081337	CV	11 98%	tylan #2	
	12 09 00	User Event		Number	1	0 3397	lpm
5	12 09 00	7 22E-02	0 084741	In duct		Both tylans	
6	12 09 35	2 77E-01	0 325115	**Both tylans on**		0 6435	lpm
7	12 10 10	1 33E-01	0 156102	**SF6 distribution**			
8	12 10 46	6 21E-01	0 728868				
9	12 11 21	1 00E+00	1 1737				
10	12 11 57	1 89E-01	0 221829				
11	12 12 32	1 05E-01	0 123239				
12	12 13 07	3 27E-01	0 3838				
13	12 13 43	3 90E-01	0 457743				
14	12 14 18	2 65E-01	0 311031				
15	12 14 53	2 20E+00	2 58214	Avg	0 576846	0 73%	Ave Eff
16	12 15 40	5 06E-01	0 593892	Std Dev	0 669933	0 16%	Min Eff
17	12 16 15	3 04E-01	0 356805	CV	116 14%	3 27%	Max Eff
	12 16 50	User Event		Number	2		
18	12 16 50	6 83E+01	80 16371	**100% capture**			
19	12 17 31	6 75E+01	79 22475	**Both tylans**			
20	12 18 06	6 57E+01	77 11209				
21	12 18 41	6 68E+01	78 40316				
22	12 19 17	6 76E+01	79 34212	Avg	79 00678	287 5139	Mean flow
23	12 19 52	6 78E+01	79 57686	Std Dev	0 985322	283 3645	Min
24	12 20 28	6 75E+01	79 22475	CV	1 25%	294 5783	Max
	12 21 03	User Event		Number	3		
25	12 21 03	5 13E+01	60 21081	**100% capture**			
26	12 21 38	3 59E+01	42 13583	**Tylan #2 only**			
27	12 22 14	3 50E+01	41 0785				
28	12 22 49	3 44E+01	40 37528	Avg	41 0795	291 9074	Mean flow
29	12 23 25	3 46E+01	40 61002	Std Dev	0 679328	284 5894	Min
30	12 24 00	3 51E+01	41 19687	CV	1 65%	296 9988	Max
********** **** COM	NT ******	******					
outdoor te st paver	oriented i	nto wind,	7/6/95				
********** * END OF	OMMENT	******					

Blaw Knox	**Outside, wind @ 90 degrees blowing @ rt. side of paver, 8-10 mph**						
- 1302 Measurement Data ------ 1788611/2803 - 1995-07-06 12 57 - Page 1 -							
1302 Settings							
Compensate for Water Vap Interference					NO		
Compensate for Cross Interference					NO		
Sample Continuously				YES			
Pre-set Monitoring Period				NO			
Measure							
Gas A Sulfur hexafluoride				YES			
Water Vapour				NO			
Sampling Tube Length				15 0 ft			
Air Pressure				760 0 mmHg			
Normalization Temperature				60 0 F			
Start Time				1995-07-06 10 58			
Stop Time				1995-07-06 11 21			
Results Not Averaged							
Number of Event Marks				3			
Number of Recorded Samples					37		
	Alarm Limit		Max	Mean	Min	Std Dev	
Gas A	________		259E+00	26 8E+00	64 9E-03	46 9E+00	
No	hh mm ss	ppm	Calibration				
-----	-------	-------	Correction				
1	10 58 37	2 85E-01	0 334505	**Background air**			
2	10 59 20	9 28E-02	0 108919				
3	10 59 55	9 71E-02	0 113966			**SF6 flow**	
4	11 00 30	7 95E-02	0 093309			**tylan #2**	
5	11 01 06	2 07E-01	0 242856			0 3397	lpm
6	11 01 41	9 44E-02	0 110797			**Both tylans**	
7	11 02 17	6 54E-02	0 07676	Avg	0 108802	0 6435	lpm
8	11 02 52	6 78E-02	0 079577	Std Dev	0 052726		
9	11 03 27	6 54E-02	0 07676	CV	48 46%		
10	11 04 03	6 49E-02	0 076173				
	11 04 03	User Event		Number	1		
11	11 04 38	3 61E+01	42 37057	In duct			
12	11 05 18	3 57E+01	41 90109	**Tylan #2 only**			
13	11 05 54	3 62E+01	42 48794	**100% capture**			
14	11 06 29	3 57E+01	41 90109				
15	11 07 04	3 58E+01	42 01846				
16	11 07 40	3 59E+01	42 13583	Avg	42 06876	285 0431	Mean flow
17	11 08 15	3 55E+01	41 66635	Std Dev	0 286353	282 2309	Min
18	11 08 51	3 50E+01	41 0795	CV	0 68%	287 796	Max
	11 09 37	User Event		Number	2		
19	11 09 37	2 59E+02	303 9883	**Both tylans on**			
20	11 10 13	6 98E+01	81 92426	**100% capture**			
21	11 10 48	7 07E+01	82 98059				
22	11 11 24	7 12E+01	83 56744				
23	11 11 59	7 15E+01	83 91955	Avg	83 37182	272 4808	Mean flow
24	11 12 34	7 15E+01	83 91955	Std Dev	0 798346	270 6825	Min
25	11 13 10	7 15E+01	83 91955	CV	0 96%	277 275	Max
	11 13 45	User Event		Number	3		
26	11 13 45	7 35E+00	8 628695	**SF6 distribution**			
27	11 14 23	4 91E-01	0 576287	**Both tylans on**			
28	11 15 01	3 89E-01	0 456569				
29	11 15 36	3 39E-01	0 397884				
30	11 16 12	2 01E-01	0 235914				
31	11 16 47	3 08E-01	0 3615				
32	11 17 23	5 23E-01	0 613845				
33	11 17 58	1 55E-01	0 181924				
34	11 18 33	4 43E-01	0 519949				
35	11 19 40	2 06E-01	0 241782	Avg	0 392336	0 47%	Ave Eff
36	11 20 15	1 86E-01	0 218308	Std Dev	0 154899	0 22%	Min Eff
37	11 20 50	4 36E-01	0 511733	CV	39 51%	0 74%	Max Eff
****	******	**** COM	NT ******	*******			
outdoor test paver oriented 90 deg with wind 7/06/95-							
****	******	* END OF	COMMEN	*******			

Blaw Knox	**Outside, wind @ 90 degrees blowing @ rt. side of paver, 8-10 mph**						
- 1302 Measurement Data —— 1788611/2803 - 1995-07-06 13 01 - Page 1 -							
1302 Settings							
Compensate for Water Vap Interference				NO			
Compensate for Cross Interference				NO			
Sample Continuously			YES				
Pre-set Monitoring Period			NO				
Measure							
Gas A Sulfur hexafluoride			YES				
Water Vapour			NO				
Sampling Tube Length			15 0 ft				
Air Pressure			760 0 mmHg				
Normalization Temperature			80 0 F				
Start Time		1995-07-06 12 29					
Stop Time		1995-07-06 12 42					
Results of Event	Marks		2				
Number of Record	ed Sampl		21				
Number of Recorded Samples			21				
	Alarm Limit	Max	Mean	Min	Std Dev		
Gas A	________	35 8E+00	9 92E+00	67 3E-03	15 4E+00		
Samp No	Time hh mm ss	Gas A ppm	Calibration Correction				
1	12 30 01	2 11E-01	0 247651	**Area background**			
2	12 30 43	8 05E-02	0 094483	Avg	0 08615		
3	12 31 19	7 24E-02	0 084976	Std Dev	0 007813	**SF6 flow**	
4	12 31 54	6 73E-02	0 07899	CV	9 07%	tylan #2	
	12 32 30	User Even	#VALUE!	Number	1	0 3397	lpm
5	12 32 30	2 74E+01	32 15938	**100% capture**		Both tylans	
6	12 33 10	3 56E+01	41 78372	**Tylan #2 only**		0 6435	lpm
7	12 33 45	3 50E+01	41 0795				
8	12 34 21	3 55E+01	41 66635	Avg	41 6194	288 1207	Mean flow
9	12 34 56	3 54E+01	41 54898	Std Dev	0 348176	285 3843	Min
10	12 35 31	3 58E+01	42 01846	CV	0 84%	291 9074	Max
	12 36 07	User Even	#VALUE!	Number	2		
11	12 36 07	3 37E-01	0 395537	**Both tylans on**			
12	12 36 47	4 98E-01	0 584503	**SF6 distribution**			
13	12 37 22	5 16E-01	0 605629				
14	12 37 58	2 69E-01	0 315725				
15	12 38 33	3 05E-01	0 357979				
16	12 39 08	1 75E-01	0 205398				
17	12 39 44	2 60E-01	0 305162				
18	12 40 30	2 20E-01	0 258214				
19	12 41 06	2 25E-01	0 264083	Avg	0 344748	0 42%	Ave Eff
20	12 41 41	1 85E-01	0 217135	Std Dev	0 135733	0 25%	Min Eff
21	12 42 16	2 41E-01	0 282862	CV	39 37%	0 73%	Max Eff
**********	**** COM	NT *******	*******				
outdoor tester, paver oriented 90 deg with wind, 7/6/95							
**********	* END OF	OMMENT	*******				

Blaw Knox | **Outside, wind @ 180 degrees blowing @ rear of paver, 8-10 mph**

- 1302 Measurement Data —— 1788611/2803 - 1995-07-06 12 58 - Page 1 -

1302 Settings	
Compensate for Water Vap Interference	NO
Compensate for Cross Interference	NO
Sample Continuously	YES
Pre-set Monitoring Period	NO
Measure	
Gas A Sulfur hexafluoride	YES
Water Vapour	NO
Sampling Tube Length	15 0 ft
Air Pressure	760 0 mmHg
Normalization Temperature	80 0 F
Start Time	1995-07-06 11 26
Stop Time	1995-07-06 11 53
Results Not Averaged	
Number of Event Marks	5
Number of Recorded Samples	44

	Alarm Limit	Max	Mean	Min	Std Dev
Gas A	________	73 9E+00	22 7E+00	58 3E-03	27 0E+00

Samp No	Time hh mm ss	Gas A ppm	Calibration Correction				
1	11 26 51	8 24E-02	0 096713	**Area background**			
2	11 27 34	6 93E-02	0 081337				
3	11 28 10	6 04E-02	0 070891			**SF6 flow**	
4	11 28 45	6 45E-02	0 075704			tylan #2	
5	11 29 20	6 50E-02	0 076291			0 3397	lpm
6	11 29 56	6 74E-02	0 079107			Both tylans	
7	11 30 31	6 02E-02	0 070657			0 6435	lpm
8	11 31 06	6 51E-02	0 076408				
9	11 31 42	5 83E-02	0 068427	Avg	0 076771		
10	11 32 17	6 08E-02	0 071361	Std Dev	0 006524		
11	11 32 53	7 63E-02	0 089553	CV	8 50%		
12	11 33 28	7 22E-02	0 084741				
	11 33 28	User Event		Number	1		
13	11 34 03	8 14E+00	9 553918				
14	11 34 41	2 72E+00	3 192464				
15	11 35 16	3 83E+00	4 495271	**Start SF6, both tylans**			
16	11 35 52	3 84E+00	4 507008	**SF6 distribution**			
17	11 36 27	3 87E+00	4 542219				
18	11 37 02	3 74E+00	4 389638				
19	11 37 49	3 52E+00	4 131424				
20	11 38 24	4 86E+00	5 704182				
21	11 39 00	4 24E+00	4 976488				
22	11 39 35	4 44E+00	5 211228				
23	11 40 10	3 25E+00	3 814525	Avg	4 749217	5 67%	Ave Eff
24	11 40 46	5 21E+00	6 114977	Std Dev	0 689118	4 55%	Min Eff
25	11 41 21	3 71E+00	4 354427	CV	14 51%	7 30%	Max Eff
	11 41 56	User Event		Number	2		
26	11 41 56	7 39E+01	86 73643	**100% capture**			
27	11 42 35	7 01E+01	82 27637	**Both tylans on**			

28	11 43 11	7 25E+01	85 09325						
29	11 43 46	7 14E+01	83 80218						
30	11 44 21	7 09E+01	83 21533	Avg	83 75188	271 2244	Mean flow		
31	11 44 57	7 02E+01	82 39374	Std Dev	1 634574	261 8917	Min		
32	11 45 32	7 05E+01	82 74585	CV	1 95%	276 0884	Max		
	11 46 08	User Event		Number	3				
33	11 46 08	7 26E+01	85 21062						
34	11 46 43	3 64E+01	42 72268	**Tylan #2 only**					
35	11 47 49	3 77E+01	44 24849	**100% capture**					
36	11 48 25	3 69E+01	43 30953	Avg	42 82049	280 0391	Mean flow		
37	11 49 00	3 62E+01	42 48794	Std Dev	0 876485	271 0016	Min		
38	11 49 36	3 55E+01	41 66635	CV	2 05%	287 796	Max		
39	11 50 11	3 62E+01	42 48794						
	11 50 11	User Event		Number	4				
40	11 50 47	6 18E-01	0 725347	**Pull #2 tylan tubing**					
	11 51 27	User Event		Number	5				
41	11 51 27	3 99E+01	46 83063	**Put #2 back, pull #3**					
42	11 52 07	3 60E+01	42 2532	Avg	43 95507	272 8107	Mean flow		
43	11 52 43	3 78E+01	44 36586	Std Dev	2 148224	256 0591	Min		
44	11 53 18	3 61E+01	42 37057	CV	4 89%	283 7989	Max		
**********	****COM	NT *******	*******						
outdoor te	7/6/95								
**********	* END OF	OMMENT	*******						

Blaw Knox **Outside, wind @ 270 degrees blowing @ lt side of paver, 8-10 mph**

- 1302 Measurement Data ---- 1788611/2803 - 1995-07-06 12 51 - Page 1 -

1302 Settings	
Compensate for Water Vap Interference	NO
Compensate for Cross Interference	NO
Sample Continuously	YES
Pre-set Monitoring Period	NO
Measure	
Gas A Sulfur hexafluoride	YES
Water Vapour	NO
Sampling Tube Length	15 0 ft
Air Pressure	760 0 mmHg
Normalization Temperature	80 0 F
Start Time	1995-07-06 09 47
Stop Time	1995-07-06 10 23
Results Not Averaged	
Number of Event Marks	5
Number of Recorded Samples	59

	Alarm Limit	Max	Mean	Min	Std Dev
Gas A	________	71 5E+00	14 8E+00	50 4E-03	25 3E+00

Samp No	Time hh mm ss	Gas A ppm	Calibration Correction				
1	9 47 34	7 41E-02	0 086971	**Area background**			
2	9 48 17	7 64E-02	0 089671				
3	9 48 52	1 01E+00	1 185437			**SF6 flow**	
4	9 49 27	7 01E-02	0 082276			**tylan #2**	
5	9 50 03	2 32E-01	0 272298			0 3397	lpm
6	9 50 38	3 49E-01	0 409621			**Both tylans**	
7	9 51 13	1 13E-01	0 132628			0 6435	lpm
8	9 51 49	3 53E-01	0 414316				
9	9 52 24	3 40E-01	0 399058				
10	9 52 59	6 29E-02	0 073826				
11	9 53 35	6 17E-02	0 072417				
12	9 54 10	6 42E-02	0 075352				
13	9 55 17	5 71E-02	0 067018	Avg	0 072143		
14	9 55 52	6 47E-02	0 075938	Std Dev	0 003703		
15	9 56 27	5 82E-02	0 068309	CV	5 13%		
	9 57 03	User Event		Number	1		
16	9 57 03	5 90E-02	0 069248	**In duct**			
17	9 57 38	6 19E-02	0 072652	**No SF6**			
18	9 58 14	5 04E-02	0 059154				
19	9 58 49	5 87E-02	0 068896				
20	9 59 25	5 91E-02	0 069366				
21	10 00 00	6 10E-02	0 071596				
22	10 00 36	7 15E-02	0 08392	Avg	0 072222		
23	10 01 11	6 90E-02	0 080985	Std Dev	0 007218		
24	10 01 46	6 32E-02	0 074178	CV	9 99%		
	10 02 22	User Event		Number	2		
25	10 02 22	6 12E-02	0 07183	**In duct**			
26	10 02 57	3 80E+01	44 6006	**Tylan #2 on**			
27	10 03 38	3 65E+01	42 84005	**100% capture**			

Outside, 270

28	10 04 13	3 75E+01	44 01375						
29	10 05 08	3 76E+01	44 13112						
30	10 05 43	3 72E+01	43 66164	Avg	43 84608	273 4888	Mean flow		
31	10 06 18	3 75E+01	44 01375	Std Dev	0 545727	268 8621	Min		
32	10 06 54	3 72E+01	43 66164	CV	1 24%	279 9112	Max		
33	10 07 29	3 71E+01	43 54427						
	10 07 29	User Event		Number	3				
34	10 08 05	6 94E+01	81 45478	**In duct**					
35	10 08 40	7 02E+01	82 39374	**Tylan #2 & #3 on**					
36	10 09 15	6 99E+01	82 04163	**100% capture**					
37	10 09 51	7 09E+01	83 21533						
38	10 10 26	7 08E+01	83 09796	Avg	82 67878	274 7446	Mean flow		
39	10 11 02	7 15E+01	83 91955	Std Dev	0 81558	270 6825	Min		
40	10 11 37	7 04E+01	82 62848	CV	0 99%	276 8783	Max		
41	10 12 12	7 00E+01	82 159						
	10 12 12	User Event		Number	4				
42	10 12 48	4 96E-01	0 582155	**In duct**					
43	10 13 28	2 28E-01	0 267604	**Both tylans on**					
44	10 14 04	3 86E-01	0 453048	**SF6 in distribution**					
45	10 14 50	4 54E-01	0 53286						
46	10 15 25	6 08E-01	0 71361						
47	10 16 01	5 39E-01	0 632624						
48	10 16 36	3 56E-01	0 417837						
49	10 17 11	8 90E-01	1 044593						
50	10 17 47	4 48E-01	0 525818						
51	10 18 22	2 19E-01	0 25704						
52	10 18 57	2 06E-01	0 241782						
53	10 19 33	5 44E-01	0 638493	Avg	0 505362	0 61%	Ave Eff		
54	10 20 08	2 99E-01	0 350936	Std Dev	0 215711	0 29%	Min Eff		
55	10 20 43	3 55E-01	0 416664	CV	42 68%	1 26%	Max Eff		
	10 21 19	User Event		Number	5				
56	10 21 19	8 94E-02	0 104929	**Stop SF6**					
57	10 21 54	1 10E-01	0 129107	Avg	0 103667				
58	10 22 29	6 19E-02	0 072652	Std Dev	0 023305				
59	10 23 05	9 20E-02	0 10798	CV	22 48%				
**********	**** COM	NT *******	*******						
outdoor te	sts on 7-6	-95 Pave	r oriented	into wind	90 deg	with wind			
**********	* END OF	OMMENT	*******						

APPENDIX C

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

BLAW-KNOX PROTOTYPE DESIGN MODIFICATIONS PRIOR TO PHASE TWO FIELD EVALUATIONS

BLAW-KNOX
FAX TRANSMITTAL

Sheet 1 of 2

TO: R. Leroy Mickelsen
U.S. Dept. of Health and
Human Services
NIOSH

FAX#: (513) 841-4506

FROM: Leland J Warren
Blaw-Knox Const. Equip. Corp.
750 Broadway Avenue East
Mattoon, IL 61938-4600
(217) 234-8811 Phone
(217) 234-8827 Fax

DATE: February 1, 1996

RE: Appendix to the report on the laboratory test at Blaw-Knox.

Attached please find the "Appendix X, Equipment Manufacturer's Improvements Based on Draft Report Recommendations" for attachment to the report on your laboratory test of the Blaw-Knox prototype asphalt fume engineering control performed at Blaw-Knox. This was drafted based on the outline you supplied to Jack Farley in your FAX of December 13, 1995 Thank you for the opportunity to add this information to the report

Please keep us informed on the progress toward finalization and publication of the report and the progress and direction of the program in general I assume we will receive a copy of the final report as soon as it available

Thank you for your time and consideration

Leland J. Warren

Attachment

cc: T Roth
J Farley

Appendix X
Equipment Manufacturer's Improvements Based on Draft Report Recommendations

The exhaust system was changed by revising the collection hood configuration and adding a separate exhaust fan. The hood was revised to reduce the inlet area to increase the air velocity at the hood face to improve capture of asphalt emissions. The hood was also split into two hoods (left and right) to accommodate clearance problems A separate exhaust fan was added to provide more air flow. The clear vinyl barrier between the hoods and screed was revised to improve coverage of the auger area.

The exhaust exits the system eight (8) feet above the paver deck where the operator stations are located This will assure that it is exhausted away form the workers' breathing zone.

In previous tests, fugitive air from the engine's cooling system caused turbulence in the auger area and made the capture of asphalt emissions more difficult. This air is now diverted from the auger area by a sheet metal barrier installed in the center of the under-deck space through which the air was flowing.

The exhaust fan is rated at 2770 cubic feet per minute (cfm) free blowing and up to 6.5 inches of water static pressure Measurements taken on 11/8/95 and 1/12/96 show that the system operates at 2200 cfm under normal use conditions The flow rate was measured at the center of a straight portion of the ducting upstream of the fan using a TSI Inc. model 8630 VelociCalc Plus air velocity meter. The meter was set to the flow rate function and the probe inserted into the duct to a depth of half the duct diameter through a small hole just large enough to accept the probe This flow rate represents an 815% increase over the 270 cfm exhaust flow rate measured during the initial evaluation.

Four (4) capture velocities were measured along the top of each auger (left and right) for a total of eight (8) velocity measurements The measurements were taken 6 inches away from the face of the hood The measured values in feet per minute (fpm) were

LEFT AUGER				RIGHT AUGER			
LH Side	Center		RH Side	LH Side	Center		RH Side
91	124	110	116	106	133	158	239

The new hood dimensions are 1 75 in deep x 48 in. wide x 19 in. high. Two hoods are used, one over each auger area Eight (8) face velocity measurements (four (4) for each hood) were made across the width of the hoods These measurements, from left to right, were ·

LEFT HOOD				RIGHT HOOD			
1190	1680	1170	960	860	1070	1380	1980

All velocity measurements were conducted using a TSI Inc. Model 8630 VelociCalc Plus air velocity meter. The meter was set to the velocity function and the probe was manually positioned at the measurement locations The data was recorded using a TSI Inc Model 8925 portable printer connected to the meter

Visual studies using a Rosco model 1500 fog machine showed improved capture and better resistance to cross wind affects.